A Vegetation Map

From Satellite Imagery

for

White Sands National Monument

FINAL REPORT

to the

National Park Service

White Sands National Monument

Alamogordo, New Mexico 88310

Submitted by

Esteban Muldavin
Marisela Pando Moreno
Jamie Thompson
and
Patricia Mehlhop

New Mexico Natural Heritage Program
University of New Mexico
Albuquerque, New Mexico 87131

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INTRODUCTION

An increasing need for vegetation maps has been arising during the last two decades to address growing concerns in matters of the environment. Attention is now focused more on the balance of natural resources and changes through time; thus we need resource maps with ever increasing frequency (Morain, 1972). Vegetation maps developed with the use of satellite images can make an important contribution in the periodic inventory of resources because of their speed in development and repeatability.

Most National Parks throughout the country are dealing with the task of periodic monitoring and assessment of condition of their biological resources. However, some of them may require a more frequent evaluation depending on the fragility of their ecosystem or the human impact they are exposed to. White Sands National Monument represents both situations: a very sensitive environment subject to potential impacts from surrounding land use and from heavy public use. For example, it may require a minimum of 30 years for a stable interdune in this area to recover from the tracks made by a single heavy vehicle (Reid, 1979 as cited by Patrick, 1980).

The overall objective of this project was to generate a 1:24,000 vegetation map of White Sands National Monument using Landsat TM satellite imagery to meet the needs for natural resources management and planning, as well as for long term monitoring of vegetation change. The map resolution was targeted at major vegetation dominance types, and where possible community types (series and plant association level, respectively of the New Mexico Natural Heritage Program's statewide vegetation classification). In the process of map development, potential permanent monitoring sites were identified, and initially surveyed for vegetation composition and abundance. These sites also served to enhance the New Mexico Natural Heritage Program's (NMNHP) vegetation classification development.

STUDY AREA

The White Sands National Monument is located in south central New Mexico. Its 61,700 ha (152,400 acres) lie in the Tularosa Basin and are surrounded by the White Sands Missile Range to the north, west and south, and Holloman Air Force Base to the east (Figure 1). The western portion of the Monument is under joint jurisdiction with White Sands Missile Range (Department of Defense), but the National Park Service responsible for overall management.

The climate of the study area is typical of the northern Chihuahuan Desert with an annual average rainfall of 200 mm (8 inches), with half of the precipitation falling between July and September. According to Tuan (1973) the distribution within the Monument area is not uniform -- the east edge receives no more than 170 mm (6.8 inches) per year. The cold/dry months are from November through March, after which

Figure 1. Location of White Sands National Monument.

temperatures often reach 43.3° C (110° F). Micro-environmental conditions can vary significantly over a few meters, as temperature decreases several degrees beneath any vegetative cover, from cryptogamic crusts to cottonwoods.

Soils are predominantly sandy, and developed from eolian gypsum deposits blown in from the dry bed of Lake Lucero on the west side of the monument. Hence, much of the monument is dominated by unstable shifting sands (large parabolic and transverse dunes). On both the far western (west of Lake Lucero), and far eastern side of the Monument, soils are developed in alluvial fans and bajadas composed of limestone and sandstone alluvial sediments originating in the San Andres and Sacramento Mountains, respectively. Along the southern boundary there are areas that support soils derived from non-gypsiferous basin fill of the Tularosa Basin.

In spite of its unique environment, few vegetational studies have been conducted in the area. Among the few are those of Shields (1956) who defined species composition on gypsum dunes compared to other substrates; Echlin (1977) who described plant community structures for the area; the work of Hogg (1979) that deals with phenology of interdune communities; Reid (1980) who described plant associations related to soil groups, and Patrick (1980) who examined succession of vegetation on parabolic dunes.

The map and descriptions that follow represent the first comprehensive effort to ascertain the overall composition and distribution of the vegetation communities on the Monument.

METHODS

Mapping Process and Image Base

The vegetation map is based on a digital Landsat-5 Thematic Mapper (TM) satellite image of August 15, 1991. The fundamental unit of the image is the "pixel", a 28.5 meter on a side square of land surface that is scanned by the satellite. The satellite detectors are capable of sensing three bands of visible light -- blue, green and red (TM Bands 1,2 & 3), along with three infra-red bands -- near, mid and far (TM Bands 4, 5 & 7, respectively).

During the mapping process a set of spectral classes is defined on the basis of variation of band reflectance among the pixels. Each pixel is then assigned to a spectral class and each spectral class is correlated to a vegetation class on the ground.
Additionally, the classification can be enhanced by spatial analysis using a digital elevation model (DEM) of elevation, slope and aspect in a geographic information system (GIS).

Image Preparation

Prior to the classification several analyses were carried out:

Radiometric correction. This analysis was performed to evaluate the relationship between the individual detector output and the input scene radiance, and to correct, when necessary, distortions such as line dropouts, striping and/or line start problems.

Atmospheric correction. Atmospheric scattering and absorption usually act as sources of error which minimize our capacity to obtain useful terrain information from remotely sensed data. Hence, atmospheric adjustments were applied to the data to attenuate some of these effects. The corrections performed considered solar irradiance, atmospheric transmittance, solar zenith angle, and background reflectance.

Geometric correction. A geometric rectification is important when further analyses will be requiring precise location of positions (UTM or degrees, minutes, seconds) on the image, as was the case on this project. This process involves relating the pixel coordinates of ground control points (GCPs), such as row and column, to the map coordinate counterparts in order to perform a geometric transformation of the image. The rectification goal here was +/- one pixel error between image and map locations.

Contrast Enhancement. Detectors on most sensing systems are designed to register a wide range of feature brightness values (usually 0 - 255). Very few scenes are composed of the whole range of values. However, this results in relatively low contrast imagery with values probably ranging from 10 to 80 or 120. Different techniques can be used to improve the contrast of these data by expanding the original input brightness values to the total available range. Here, the image was enhanced by the Saturating Linear Contrast method to maximize differences among reflectance values of features of interest on the Monument.

Initial Unsupervised classification

Once the image corrections were performed, an unsupervised spectral classification was performed to obtain a first approximation of spectral classes to be compared to vegetation types in the field.

The unsupervised classification computer algorithm groups pixels on the basis of their spectral similarities. However, the classification is, to some extent, under control of the analyst since he/she can determine the statistical distance between categories which will eventually define the maximum number of classes to be generated. The unsupervised classification applied to this image was based on TM Band 2 (green), TM Band 5 (mid-infrared), Vegetation Index (ratio of TM Bands 3 to 4, red to near infrared) and Band 7 (far infrared). Twenty seven spectral classes were generated representing two to three times the estimated number of final classes that will result through the subsequent aggregation of spectral classes representing similar vegetation.

Once classified, information classes in the form of vegetation classification are associated with these spectral classes.

All image analysis and classification was performed using ERDAS version 7.0 (1990) and ERDAS IMAGINE (1993) software.

Field Verification Methods

To assign vegetation classes to spectral classes, field data on vegetation composition was collected and accurately geo-referenced using a Global Positioning System (GPS) for later direct association of spectral classes with particular sets of ground verified pixels.

Vegetation sampling

Two levels of sampling intensity were applied. In order to sample as many spectral classes as possible with maximum replication, 219 "validation" plots were established. These plots contain the minimum detail necessary to classify a site on the ground according to the NMNHP statewide vegetation classification (NMNHP 1993).

For each validation plot, the following information was gathered:

Date, Surveyors
Survey site, Plot ID
Quadrats
Photo number
Slope, Aspect, Shape, Elevation, Position
Landform, Parent material
GPS way points, Time
Landscape
Occurrence size, Condition, Viability, Defensibility
Comments
Plant Species list
Plant Species cover (ranked as follows: +=few, small cover; 1=numerous,<5%; 2=5-25%; 3=25-50%; 4=50-75%; 5=75-100%

In addition to the validation plots, 24 more detailed "releve" reconnaissance plots were established on sites representing the central concepts of each of the major community types encountered. These releves provided in depth information on the communities present, and also provided baseline data for potential monitoring sites.

At each releve site, the following type of data on soils and vegetation were collected from soil pits and from 400 square meters (20 X 20 meters) vegetation plots.

Site characteristics.

Date, Surveyors
Survey site, Plot ID
UTM coordinates, GPS way points
Directions
Elevation, Aspect, Slope, Angle to Horizon
Surface rock type, Landform
Erosion potential, Erosion type
Summary vegetation description, Site and landscape features and adjacent communities
Disturbance history and evidence
Animal-use evidence
Occurrence size, condition, viability and defensibility.

Vegetation.

Species list
Species cover
Trees, shrubs, graminoids, and forbs cover
Ground cover (soil, gravel, rock, litter, wood, basal vegetation and cryptogamic crusts)

Soils.

For each horizon, the following data were recorded:
Symbology, Depth, Boundary type,
Texture (USDA & Clay %)
Rock fraction (gravel, stone boulder)
Soil color (determined by Munsell Chart)
Structure (shape)
Consistency (plasticity, stickiness)
Pores, Roots (size quantity and location)
$CaCO_3$ reaction (effervescence), Comments.

Protocols for measurements of these attributes followed standard Natural Heritage Program, Western Region guidelines outlined by Bourgeron (1991) and the Soil Conservation

Service National Soils Handbook (SCS 1992).

<u>Plot location</u>

Maps generated from the unsupervised classification of the Landsat TM image were taken to the field to identify potential locations for validation and releve plots. Large patches of particular spectral classes were identified on the map and located on the ground -- small patches were avoided. For each selected patch, the dominant vegetation type was sampled as close to the center of the stand as possible. The use of the maps allowed the most parsimonious distribution of samples among the many different spectral and vegetation community types.

Ground positions were located using a Trimble Pathfinder Global Positioning System (GPS). This system is based on a constellation of 24 satellites orbiting the Earth at high altitude. The system works by timing how long it takes a radio signal to reach earth from a satellite and then calculating the distance. Triangulation from three or four satellites allows it to figure out the exact position of a point.

Thirty 3D position fixes at ten-second intervals were recorded on each releve plot, and at least ten 3D fixes were recorded for the validation plots. Positions were then differentially corrected to the nearest +/- 5 meters using the base station data provided by the Supervisor's office of the Lincoln National Forest in Alamogordo. Averages of corrected readings were then converted to digitized files and positions plotted over the Landsat TM image of the area.

Vegetation Analysis

Initially, voucher specimens of plant species were verified and compared against reference collections at The University of New Mexico (UNM) Herbarium. Species names follow Martin and Hutchins (1980). Vouchers are housed at UNM and are available upon request to the National Park Service. All plot data were revised accordingly, and entered into the New Mexico Natural Heritage Program statewide community computerized database.

Plots were sorted into community types based on the species composition and abundance using agglomerative cluster analysis. Euclidean distances between all pairwise combinations of plots were computed and similar plots grouped in community types. This technique places similar samples into blocks or clusters, creating a hierarchical, tree-like structure called a dendrogram (Ludwig & Reynolds, 1988). Using the cluster analysis as an initial organization tool, samples were resorted into their final community type grouping using synthesis tables (Mueller-Dombois and Ellenberg, 1974). Groups were compared to the NMNHP statewide vegetation classification and either assigned to already existing classes or defined as new types to be added to the state list. These community type designations were used in the vegetation assignment of spectral classes.

We use the term "community type" here instead of "plant association" to avoid confusion with the use of "association" to describe a map unit.

Significant occurrences, in terms of community rarity on a global basis and occurrence condition, were entered into the NMNHPs Biological and Conservation Database.

Final Image Analysis and Map Production

Due to the inherent resolution limitations of a TM Landsat image, (both original spatial resolution of 28.5 meters and the one generated from geo-correction) it is hard to know what pixel exactly corresponds to the plotted ground position. Hence, not only one, but the eight surrounding pixels were considered in correlating field vegetation classes with spectral classes.

Matching between unsupervised spectral classes and field classes is not usually 100%. Unresolved classes require a different approach, such as a supervised classification, to be discriminated and mapped. In a supervised classification, the identity and location of the community types on the land are known *a priori* either through field work (validation plots, releves), analysis of aerial photographs, maps or any other source of information.

These areas, usually called "training sites", must be carefully selected to be as homogeneous as possible in order to perform a high quality digital image classification. Every pixel is then evaluated according to the spectral response from these areas and assigned to the class to which it has the highest likelihood of belonging. Several supervised classification methods may be used to assign an unknown pixel to a class. In this case, a maximum likelihood classification was performed using 113 plots as training sites.

Additionally, a digitized elevation model (DEM) was also used to discriminate between similar spectral classes by stratifying the classifications by different elevations and slopes in a GIS.

RESULTS

Vegetation Community Classification

A total of 24 releve plots and 219 fast plots were established from July 19 to August 31, involving 54 person-days of field work. The corrected GPS position for each plot is provided in Appendix 1.

Twenty two community types among twelve Series were identified for the area, based on the cluster analysis and synthesis of these plots. The cluster analysis was based on 100 of the most common species selected among those encountered in the sampling (Appendix 2). Utilizing the cluster analysis as a starting point, plots were grouped into community types on a synthesis table, and then averages within community types computed and presented as a summary table in Appendix 3.

A provisional classification of the vegetation based on the summary table is presented in Table 1. The classification has seven levels in its hierarchy:

I.Class -- major physiognomic type; a UNESCO term similar to Formation, e.g. forest, grassland etc. (Driscoll et al. 1984)

II. Sub-class -- moisture and temperature defined sub-formations

III. Regional Biome -- biogeographically related Series Groups; similar to Brown, Lowe and Pase's (1979) Biome

IV. Series Group -- sets of morphological, environmental or floristically related series

V. Series -- sets of Community Types related by at least a common dominant

VI. Community Type -- fundamental repeated assemblages of species; synonymous with plant association

VII. Phase -- floristic variants of Community Types -- Typic Phase refers to the modal species composition of the Community Type

A description of the landscape, soils, and major composition characteristics of the community types is presented below.

Table 1. A Preliminary Vegetation Classification for White Sands National Monument. The classification is hierarchically arranged from Class (Level I) to Community Type (CT) and Phase (see text). Common names along with scientific names, and six-letter acronyms of genus and species are given.

I. SHRUBLAND

II. XEROPHYTIC SHRUBLAND

III. Chihuahuan Desert Shrubland

IV. Chihuahuan Evergreen Scrub

V. *Larrea tridentata* (creosote bush) Series

Larrea tridentata/Muhlenbergia porteri CT
(LARTRI/MUHPOR; creosote bush/bush muhly)

*Larrea tridentata/*Sparse CT
(LARTRI/Sparse; creosote bush/sparse ground cover)

Typic Phase

Prosopis glandulosa Phase
(PROGLA; honey mesquite)

Flourensia cernua Phase
(FLOCER; tarbush)

IV. Chihuahuan Deciduous Scrub

V. *Flourensia cernua* (tarbush) Series

Flourensia cernua/Muhlenbergia porteri CT
(FLOCER/MUHPOR; tarbush/bush muhly)

Flourensia cernua/Sporobolus airoides CT
(FLOCER/SPOAIR; tarbush/alkali sacaton)

V. Prosopis glandulosa (honey mesquite) Series

Prosopis glandulosa/Gutierrezia sarothrae CT
(PROGLA/ATRCAN;honey mesquite/broom snakeweed)

Prosopis glandulosa/Sporobolus airoides CT
(PROGLA/SPOAIR; honey mesquite/alkali sacaton)

Prosopis glandulosa/Lycium parviflorum CT

(PROGLA/LYCPAR; honey mesquite/desert thorn)

Table 1. Continued.

III. Great Basin Desert Shrubland

IV. Great Basin Broad-leaved Scrub

V. *Atriplex canescens* (fourwing saltbush) Series

Atriplex canescens/Sporobolus airoides CT
(ATRCAN/SPOAIR; fourwing saltbush/alkali sacaton)

Typic Phase

Allenrolfea occidentalis Phase
(ALLOCC; pickleweed)

Scleropogon brevifolius Phase
(SCLBRE; burrograss)

Atriplex canescens/Sporobolus nealleyi CT
(ATRCAN/SPONEA; fourwing saltbush/gypgrass)

Atriplex canescens/Suaeda torreyana CT
(ATRCAN/SUATOR; fourwing saltbush/Torrey seepweed)

III. Other Xerophytic Shrubland Communities

IV. Alkali Flats

V. *Allenrolfea occidentalis* (pickleweed) Series

*Allenrolfea occidentalis/*Sparse CT
(ALLOCC/Sparse; pickleweed/sparse ground cover)

Allenrolfea occidentalis/Suaeda torreyana CT
(ALLOCC/SUATOR; pickleweed/Torrey seepweed)

V. *Coldenia hispidissima* (hairy coldenia) Series

Coldenia hispidissima/Selinocarpus lanceolatus CT
(COLHIS/SELLAN; hairy coldenia/gyp moonpod)

IV. Gypsum Dunes

V. *Poliomintha incana* (rosemary mint) Series

Poliomintha incana/Muhlenbergia pungens CT
(POLINC/MUHPUN; rosemary-mint/sandhill muhly)

Typic Phase

Bouteloua breviseta Phase
(BOUBRE; gyp grama)

Populus fremontii Phase
(POPFRE; Fremont cottonwood)

V. *Rhus microphylla* (littleleaf sumac) Series

Rhus microphylla/Bouteloua breviseta CT
(RHUMIC/BOUBRE; littleleaf sumac/gyp grama)

Table 1. Continued.

II. Mesophytic Shrubland

III. Plains-Mesa Sand Scrub

IV. Evergreen Microphyllous Plains-Mesa Sand Scrub

V. *Psorthamnus scoparius* (broom dalea) Series

Psorthamnus scoparius/Sporobolus contractus CT
(PSOSCO/SPOCON; broom dalea/spike dropseed)

I. GRASSLAND

II. XEROPHYTIC GRASSLAND

III. Great Basin Desert Grassland

IV. Lowland Grasslands

V. *Sporobolus airoides* (alkali sacaton) Series

Sporobolus airoides/Asclepias subverticillata CT
(SPOAIR/ASCSUB; alkali sacaton/poison milkweed)

Sporobolus airoides/Ephedra torreyana CT
(SPOAIR/EPHTOR; alkali sacaton/Torrey mormontea)

Sporobolus airoides/Sparse CT
(SPOAIR/Sparse; alkali sacaton/sparse ground cover)

V. *Oryzopsis hymenoides* (indian ricegrass) Series

Oryzopsis hymenoides/Abronia angustifolia CT
ORYHYM/ABRANG; indian ricegrass/sand verbena)

III. Other Grassland Communities

IV. Gypsum Grasslands

V. *Bouteloua breviseta* (gypsum grama) Series

Bouteloua breviseta/Schizachyrium neomexicanum CT
(BOUBRE/SCHNEO; gypsum grama/New Mexico bluestem)

Typic Phase

Coldenia hispidissima Phase
(COLHIS; coldenia)

Frankenia jamesii Phase
(FRAJAM; frankenia)

Heliotropium greggii Phase
(HELGRE; heliotrope)

Tamarix gallica Phase
(TAMGAL; saltcedar)

Table 1. Continued.

Bouteloua breviseta/Sporobolus airoides CT
(BOUBRE/SPOAIR; gypsum grama/alkali sacaton)

V. *Sporobolus nealleyi* (gypgrass) Series

Sporobolus nealleyi/Coldenia hispidissima CT
(SPONEA/COLHIS; gypgrass/coldenia)

V. *Schizachyrium neomexicanum* (New Mexico bluestem) Series

Schizachyrium neomexicanum/Abronia angustifolia CT
(SCHNEO/ABRANG; New Mexico bluestem/sand verbena)

Schizachyrium neomexicanum/Oryzopsis hymenoides CT
(SCHNEO/ORYHYM; New Mexico bluestem/indian ricegrass)

Schizachyrium neomexicanum/Sporobolus airoides CT
(SCHNEO/SPOAIR; New Mexico bluestem/alkali sacaton)

I. Riparian/Wetlands

II. Riparian

III. Southwest Riparian

IV. Forest and Woodlands

V. *Populus fremontii* (Fremont cottonwood) Series

Populus fremontii/Baccharis glutinosa CT
(POPFRE/BACGLU; Fremont cottonwood/seepwillow)

Populus fremontii/Oryzopsis hymenoides CT
(POPFRE/BACGLU; Fremont cottonwood/indian ricegrass)

IV. Shrublands

V. *Tamarix gallica* (salt cedar) Series

Tamarix gallica/Allenrolfea occidentalis CT
(TAMGAL/ALLOCC; saltcedar/pickleweed)

Typic Phase

Sporobolus airoides Phase
(SPOAIR; alkali sacaton)

Tamarix gallica/Distichlis spicata CT
(TAMGAL/DISSPI; saltcedar/salt grass

Typic Phase

Baccharis glutinosa Phase
(BACGLU; seepwillow)

*Tamarix gallica/*Sparse CT
(TAMGAL/SPARSE; saltcedar/sparse ground cover

Table 1. Continued.

III. Arroyo Riparian

IV. Shrublands

V. *Rhus aromatica* Series

Rhus aromatica/Sporobolus airoides CT
(RHUARO/SPOAIR; sweet sumac/alkali sacaton)

Vegetation Communities of White Sands National Monument -- An Overview.

SHRUBLANDS

Xerophytic Shrublands

Chihuahuan Desert Shrubland

This biome occurs extensively in southern New Mexico, west Texas and northeastern to north-central Mexico. Within the Monument it occurs on alluvial fans over large areas of the far western side. Two series groups have been identified: the Evergreen scrub group represented by the Creosote Bush Series, and the deciduous scrub group represented by the Tarbush and Honey Mesquite Series. Overall, seven community types were identified for the biome.

Larrea tridentata (creosote bush) Series

Two community types were identified in this Series: *Larrea tridentata*/Sparse (Creosote Bush/Sparse) and *Larrea tridentata/Muhlenbergia porteri* (creosote bush/bush muhly). In the sparse type, there is very little vegetation in the understory; while in the *Muhlenbergia porteri* type, forbs and grasses do occur, but are restricted to areas beneath the shrubs and are absent in the intershrub areas. A sandy or gravelly soil surface with no cryptogamic crust is characteristic of these community types. They generally occur on lower alluvial fans and piedmonts (bajadas).

Prosopis glandulosa (honey mesquite) and *Flourensia cernua* Phases were also identified within the *Larrea tridentata*/Sparse CT. The *Prosopis* phase may represent an ecotone to the *Prosopis glandulosa* Series that occurs on dunelands. Similarly, the *Flourensia* Phase may represent a transition to the *Flourensia* Series which can dominate alluvial flats and bottoms lower in the landscape.

Flourensia cernua (tarbush) Series

The Tarbush Series is represented by two major community types. The *Flourensia cernua/Sporobolus airoides* (tarbush/alkali sacaton) CT occurs on the bottom toe slopes of alluvial fans and basin bottom flats. It is commonly found on slightly elevated islands which are surrounded by washes, creating a dendritic drainage pattern. The understory is usually dominated by *Gutierrezia sarothrae* (snakeweed) while grasses other than *S. airoides* are noticeably absent. The main forb components are *Lepidium montanum* and *Salsola kali*.

The other community type, the *Flourensia cernua/Muhlenbergia porteri* (Tarbush/Bush Muhly) CT, is mainly found on lower alluvial fans. *Atriplex canescens* (fourwing saltbush) is a codominant shrub species, with bush muhly and other grasses commonly growing under the shrubs and occasionally out into the intershrub spaces.

Prosopis glandulosa (honey mesquite) Series

The *Prosopis glandulosa* Series occurs on large areas at the western margin of the Monument and is represented by three community types. The predominant landform is usually that of coppice dunes located on the toeslopes of San Andres Mountains alluvial fans.

A small dune landscape characterizes the *Prosopis glandulosa/ Atriplex canescens* (honey mesquite/fourwing saltbush) CT -- *Gutierrezia sarothrae* (snakeweed) Phase. Average dune size is 2m X 6m with honey mesquite growing out of it. The dunes form around the mesquite, while fourwing saltbush bushes hug the margins of the dunes and *G. sarothrae* occupies the interdune areas.

The *Prosopis glandulosa*/*Sporobolus airoides* (honey mesquite/alkali sacaton) CT has a very restricted distribution on the western side of the Monument. The characteristic landform for this community type is very low dunes not exceeding 1m in height. The dunes are stabilized by mesquite with the alkali sacaton growing in the interdune spaces.

In contrast to the coppice dune communities, the *Prosopis glandulosa*/*Lycium parviflorum* (honey mesquite/desert thorn) CT occurs in a basin bottom with very thin sandy soils with a caliche layer near the surface (30 cm deep). The inter-shrub zone shows almost no vegetation, although it exhibits extensive cryptogam cover.

Great Basin Desert Shrubland

The Great Basin Desert Scrub biome occurs here as an extension out of the Plateau region of northwestern New Mexico. It is represented by the *Atriplex canescens* (fourwing saltbush) Series of the Broad-leaved Scrub Series Group, encompassing three community types which occur on the flats surrounding the dunelands and in the larger interdunal areas.

Atriplex canescens (fourwing saltbush) Series

Two major community types occur in the area within this Series. The *Atriplex canescens/Sporobolus airoides* (fourwing saltbush/alkali sacaton) CT is found mainly on alluvial flats and bajadas with fairly uniform topography. Grassy hummocks of alkali sacaton occur in the intershrub zones along with crusty exposed soil.

The *Atriplex canescens/Sporobolus nealleyi* (fourwing saltbush/gypgrass) CT occurs in more sandy conditions with abundant gypgrass and cryptogamic cover in the intershrub zone. This may be a locally restricted community type.

Additionally, an *Atriplex canescens/Suaeda torreyana* (fourwing saltbush/Torrey seepweed) CT occurred on alkali flats on the western side. This type may be a minor variant of the *Allenrolfea occidentalis/Suaeda torreyana* type described below, which is also found on alkali flats.

Other Xerophytic Shrubland Communities

Alkali Flats and Gypsum Outcrops

Allenrolfea occidentalis (pickle weed) Series

The *Allenrolfea occidentalis*/Sparse (pickleweed/sparse ground cover) and *Allenrolfea occidentalis/Suaeda torreyana* (pickleweed/torrey seepweed) shrubland communities are the dominant communities of the extensive flats found on the western side of the Monument. Much of this area is an extension of the barren bottom of Lake Lucero. Seasonal inundation of water is common, and salt concentration in the soil is probably high. The water table is usually at 20 cm below the surface. Almost no other species are present except for scattered *Tamarix* (saltcedar) shrubs.

Coldenia hispidissima (hairy coldenia) Series

This Series is represented by the *Coldenia hispidissima/Selinocarpus lanceolatus* (hairy coldenia/gyp moonpod) CT which occurs on scattered low outcrops of gypsum that occur on the flats of the western side of the Monument. This type is closely related to the *Sporobolus nealleyi/Coldenia hispidissima* (gypgrass/hairy coldenia) described below, but it lacks the significant grass cover of the former.

Gypsum Dunes

Vegetation distribution on Gypsum Dunes is dependent on the relative size of the dunes and interdune areas which in turn affects water accumulation and water availability. Large areas of the dunes are nearly devoid of vegetation, or have very scattered individuals, and have been designated as Barren Dunes. Other dunes are well vegetated by shrub-dominated communities primarily of the *Poliomintha incana* Series (particularly on the perimeter of the major dune field of the Monument), and more uncommonly by the *Rhus microphylla* (littleleaf sumac).

Poliomintha incana (rosemary mint) Series

The *Poliomintha incana/Muhlenbergia pungens* (rosemary mint/sandhill muhly) CT is unique to the Monument and surrounding dunal areas on White Sands Missile Range (WSMR). It occurs on the top and faces of the dunes in areas that appear to be partially stabilized and that undergo only moderate dune movement. *Poliomintha incana* dominates the crest of the dune with *Rhus trilobata* (three leaved sumac), while *Muhlenbergia pungens* and *Oryzopsis hymenoides* (indian rice grass) grow between the clumps of shrubs. A grassier *Bouteloua breviseta* (gyp grama) phase of smaller dunes has also been identified. Occasionally *Populus fremontii* (Fremont cottonwood) is well represented as distinct phase, presumably the remnant expression of riparian interdunal *P. fremontii* communities that have now been buried by shifting dunes.

Rhus microphylla (littleleaf sumac) Series

This is a minor Series in the Monument and is represented by the *Rhus microphylla/Bouteloua breviseta* (littleleaf sumac/gyp gram) CT of low dunes and interdunal areas. *Sporobolus airoides* (alkali sacaton) is a common associate.

Mesophytic Shrublands

Evergreen Microphyllous Plains-Mesa Sand Scrub

Psorthamnus scoparius (broom dalea) Series

This Biome and Series Group is known primarily from the eastern side of New Mexico, and is represented here by the *Psorthamnus scoparius/sporobolus contractus* (broom dalea/spike dropseed) CT. This type occurs on both gypsiferous and non-gypsiferous sand dunes on the Monument, and in other dunal areas of New Mexico. The dunes are partially stabilized by the *Psorthamnus* and can have a relatively high diversity of grasses and forbs.

GRASSLAND

We have identified six community types among five grassland series. Two, the *Sporobolus airoides* (alkali sacaton) and the *Oryzopsis hymenoides* (indian ricegrass) Series, are representatives of the Great Basin Lowland Grasslands Biome; the other three series are represented by gypsiferous community types and are classified under Other Grassland Communities.

Great Basin Desert Lowland Grasslands

Sporobolus airoides (alkali sacaton) Series

The *Sporobolus airoides* Series encompasses three major community types of the Monument. The *Sporobolus airoides/Asclepias subverticillata* (alkali sacaton/poison milkweed) and the *Sporobolus airoides/Ephedra torreyana* (alkali sacaton/Torrey mormontea) CTs can have very luxuriant cover of grass (80%+), but they are very low in species richness -- commonly there are only a few scattered shrubs or forbs among nearly mono-specific stands of *S. airoides.* The types occur over extensive areas in depressions and low areas of the flats surrounding the dunes.

The *Sporobolus airoides*/Sparse CT is also represented in the area intermixed with the preceeding community type. These almost pure stands of *Sporobolus airoides* are found on very low gypsum dunes (30 cm high), and in interdune areas. Lower vegetation cover (< 25%) along with low species richness characterizes this community.

Other Grassland Communities

Gypsum Grasslands

Bouteloua breviseta (gyp grama) Series

The major grassland community type typical of gypsum interdunal areas is *Bouteloua breviseta/Schizachyrium neomexicanum* (Gyp Grama/New Mexico Bluestem). This community type is possibly unique to the Monument and surrounding WSMR, and occurs in a mosaic of distinct micro-landforms which include very low dunes (< 1 m high), flats, elevated plains and wind eroded lowlands. Small hummocks of relatively stable sand are surrounded by depressions that accumulate water and salts. Several other species are usually present in this community type with *Heliotropium greggii, Frankenia jamesii* and *Coldenia hispidissima* forming distinct phases. Bare soil is also a main component of this community type, sometimes with a well developed cryptogamic crust. Dune movement has a distinct impact on vegetation expression in this type with recently exposed sites are dominated by *Heliotropium*, and the older sites progressively dominated by *Frankenia*, and then grasses, which in turn become buried by progressing dune crests. The exotic *Tamarix gallica* (saltcedar) can also invade these sites, creating a distinct shrubby phase.

Interdunal sites that are more stable are commonly dominated by the *Bouteloua breviseta/Ephedra torreyana* (gyp grama/Torrey mormon tea) and the *Bouteloua breviseta/Sporobolus airoides* (gyp grama/alkali sacaton) CTs. These communities are more uniform and lower in diversity, lacking significant shrub or forb species.

Sporobolus nealleyi (gypgrass) Series

The *Sporobolus nealleyi/Coldenia hispidissima* (gypgrass/hairy coldenia) CT occurs on gypsum outcrops on a basin bottom. Sequential small hills and valleys with some exposed cliffs define the distribution of the species, with *Coldenia hispidissima* mainly occupying the hills and *Sporobolus nealleyi* in the lower positions. The soil surface is crusty, with an extensive cryptogamic structure.

Schizachyrium neomexicanum (New Mexico bluestem) Series

Two closely related community types, both taxonomically and spatially, have been identified in the area from this Series: the *Schizachyrium neomexicanum/Abronia angustifolia* (New Mexico bluestem/sand verbena) and the *Schizachyrium neomexicanum/ Oryzopsis hymenoides* (New Mexico bluestem/indian rice grass) CTs. Both occur in interdune areas of very sparse vegetation. The *Schizachyrium neomexicanum/Abronia angustifolia* CT dominates the dune margins, with the *Schizachyrium neomexicanum/Oryzopsis hymenoides* CT towards the center of the interdune basins. A high water table is common in these sites and may be limiting species distribution and growth.

The *Schizachyrium neomexicanum/Sporobolus airoides* (New Mexico bluestem/alkali sacaton) CT is a minor type that occurs in the larger interdunal areas. It has a higher cover of grass and is closely related to the *Bouteloua breviseta/Sporobolus airoides* CT.

RIPARIAN/WETLANDS

Southwestern Riparian Forest and Woodlands

***Populus fremontii* (cottonwood) Series**

This riparian Series is represented by two community types. The *Populus fremontii/Baccharis glutinosa* (Fremont Cottonwood/Seep Willow) CT is restricted on the Monument to small gypsum interdune areas where water accumulates and the water table remains relatively near the surface. Although the type is relatively common elsewhere in New Mexico, this is an unusual environment for this type -- normally it is found along large river floodplain corridors. According to Reid (1979), cottonwood has been able to become established in this environment due to its ability to survive both being buried as dunes advance, and having its root system exposed when deflation of the dune occurs. On occasion, dunes move over a site supporting this community, leaving only the tops of cottonwood trees as remnants of the buried community. A high diversity of species occur in this densely vegetated (about 40% cover) community type with other riparian wetland/riparian indicators such as *Juncus torreyi* (Torrey's rush) and *Salix goodingii* (Gooding willow)

The *Populus fremontii/Oryzopsis hymenoides* CT occurs in the larger, more open interdunal areas of the Monument. Herbaceous species richness and cover is much lower in this type -- the ground cover may be very sparse or absent.

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Southwestern Riparian Shrublands

***Tamarix gallica* (salt cedar) Series**

The only series so far identified for this type of shrubland is the exotic *Tamarix gallica* (saltcedar) Series. *Tamarix* is a Eurasian species that was imported earlier in this century to combat soil erosion in the western U.S. It aggressively colonizes disturbed sites, and since the time of introduction it has become extensively naturalized, displacing native riparian species (on the Monument it may displacing willow and cottonwood).

Three community types have been identified. The *Tamarix gallica/Allenrolfea occidentalis* (Saltcedar/Pickle Weed) is the most extensive community, occupying the western and central alkali flats of the Monument. The native pickle weed forms the shrub component of the community. Both species show a very sparse cover, and the herbaceous layer is commonly absent.

The *Tamarix gallica/Distichlis spicata* (saltcedar/salt grass) is characterized by a moderate open shrub canopy and high cover grassy undergrowth. It is restricted to small concave areas and drainages which are subject to episodic flooding during the year. Almost no other species are present in this community type when one or both species have high cover.

The *Tamarix gallica/*Sparse (saltcedar/sparse ground cover) CT has closed shrub canopy with little or no undergrowth. It also occurs along drainages subject to episodic flooding.

Arroyo Riparian Shrublands

Rhus aromatica (sweet sumac) Series

This is a minor series represented by the *Rhus aromatica/Sporobolus airoides* (sweet sumac/alkali sacaton) community type. It occurs along drainages that are episodically flooded. *Rhus* dominates the shrub layer with a grassy understory. Overall diversity is low.

White Sands National Monument Vegetation Map

A 1:24,000 scale vegetation map was produced based on a combination of an unsupervised classification and a supervised classification, and was stratified using a digital elevation model. The map is presented as two accompanying sheets which cover the North and South halves of the Monument, respectively. The map is also available in a digital format for entry into a GIS and further reproduction at any chosen scale or size.

Fifteen map units were defined in terms of the vegetation classification presented above. In addition there were two, non-vegetated units: Playas -- representing the bottom of Lake Lucero, and Bare Dunes for the large areas of non-vegetated duneland in the heart of the Monument. Table 2 lists the map units as they are presented on the map sheet legends. Map units are referred to as Consociations, Associations, Complexes and Undifferentiated Groups. A Consociation refers to a map unit that is dominated by a single community type, although minor inclusions can occur. An Association refers to a map unit composed of two or more community types that have a known spatially distinct pattern on the ground; however, this pattern is not mappable at this scale. A Complex refers to a map unit composed of two or more community types that are identifiable, but the spatial pattern is not known. An Undifferentiated Group refers to a map unit where community types have not been fully defined for the group. Even Consociations can have inclusions of other community types as long as a given inclusion does not exceed 10% of the map unit composition. Possible inclusions for each map unit are given in Table 2.

All of the 247 precisely geo-referenced ground points gathered during the field survey were needed to assign the spectral classes and define the map units -- no independent ground sample was available for an accuracy assessment. This ensured the highest possible initial resolution to the map with the expectation that there will be later follow up field sampling for accuracy assessment, which will lead to revision and continued updating of the map.

Potential Monitoring Sites

In the course of describing and mapping the vegetation, we established twenty two detailed releve plots on a wide variety of sites among the most important communities of the Monument. Twenty of these plots we consider good potential sites for monitoring vegetation changes in response to management or natural causes such as climate change. Complete information on species composition and abundance for each plot as well as their geo-corrected position are given in Appendix 4.

Table 2. Annotated legend for the White Sands National Monument Vegetation Map. See text for definition of Consociation, Association, Complex and Undifferentiated Group. "Incl:" refers to community type inclusions that are less than 10% of the map unit composition. "Distr:" refers to the distribution of the map unit within the monument.

<u>Alkali Flat Shrubland</u>

Salt Cedar/Pickle Weed Consociation
(*Tamarix gallica/Allenrolfea occidentalis*)

Incl: Salt Cedar/Salt Grass
(*Tamarix gallica/Distichlis spicata)*
Salt Cedar/Sparse Ground Cover
(*Tamarix gallica/*Sparse)
Fragrant Sumac/Alkali Sacaton
(*Rhus aromatica/Sporobolus airoides)*

Distr: western playa lake flats associated with Lake Lucero; eastern drainages.

Pickle Weed/Torrey Seepweed -- Pickle Weed/Sparse Complex
(*Allenrolfea occidentalis/Suaeda torreyana -- Allenrolfea occidentalis/Sparse*)

Incl: Freemont Cottonwood/Indian Ricegrass
(*Populus fremontii/Oryzopsis hymenoides*)
Barren Playa

Distr: western playa lake flats associated with Lake Lucero; Garton Lake.

<u>Gypsum Dunes Shrubland</u>

Rosemary Mint/Sandhill Muhly Consociation
(*Poliomintha incana/Muhlenbergia pungens*)

Incl: Gyp Grama/New Mexico Bluestem
(Bouteloua breviseta/Schizachyrium neomexicanum)
Fremont Cottonwood/Indian Ricegrass
(*Populus fremontii/Oryzopsis hymenoides)*
Broom Dalea/Spike Dropseed
(Psorthamnus scoparius/Sporobolus contractus)
Littleleaf Sumac/Gyp Grama
(Rhus microphylla/Bouteloua breviseta)
Barren Dunes

Distr: southern and eastern transverse and parabolic dunes; Fremont cottonwood/indian ricegrass and littleleaf sumac/gyp grama types occur in small interdunal areas; gypgrama/New Mexico bluestem occurs along margins of dunes; broom dalea/spike dropseed type is associated with low dunes that can be non-gypsiferous.

Fourwing Saltbush Shrubland

Fourwing Saltbush/Alkali Sacaton Consociation
(*Atriplex canescens/Sporobolus airoides*)

Incl:Alkali Sacaton/Poison Milkweed
(Sporobolus airoides/Asclepias subverticillata)

Distr: non-dunal eastern and southern flats

Table 2 (Continued).

Fourwing Saltbush/Gypgrass Consociation
(*Atriplex canescens/Sporobolus nealleyi*)

Incl:Gypgrass/Hairy Coldenia
(Sporobolus nealleyi/Coldenia hispidissima)

Distr: southwestern non-dunal flats

Fourwing Saltbush/Alkali sacaton- Fourwing Saltbush/Gypgrass Association
(*Atriplex canescens/Sporobolus airoides- Atriplex canescens/ Sporobolus nealleyi*)

Incl:Fourwing Saltbush/Torrey Seepweed
(Atriplex canescens/Suaeda torreyana)

Pickle Weed/Torrey Seepweed)
(Allenrolfea occidentalis/Suaeda torreyana)

Distr: non-dunal eastern and southern flats and the western fringes of Lake Lucero; lower areas tend to be occupied by the fourwing/alkali sacaton type, while the fourwing/gypgrass community occupies the slightly elevated terrain.

Mesquite Shrubland

Mesquite/Broom Snakeweed Consociation
(*Prosopis glandulosa/Gutierrezia sarothrae*)

Distr: western lower alluvial fans; scattered on western non-dunal flats.

Mesquite/Alkali Sacaton Consociation
(*Prosopis glandulosa/Sporobolus airoides*)

Incl:Tarbush/Alkali Sacaton
(Flourensia cernua/Sporobolus airoides)
Creosote Bush/Sparse Ground Cover
*(Larrea tridentata/*Sparse)

Distr: southwestern non-dunal flats and western margin of Lake Lucero.

Mesquite/Desert Thorn Consociation
(*Prosopis glandulosa/Lycium parviflorum*)

Distr: southwestern non-dunal flats.

Creosote Bush Shrubland

Creosote Bush Series/Tarbush Series Undifferentiated Group
(*Larrea tridentata/Flourensia cernua*)

Incl:Creosote Bush/Bush Muhly
(*Larrea tridentata/Muhlenbergia porteri)*
Creosote Bush/Sparse Ground Cover
*(Larrea tridentata/*Sparse)
Tarbush/Bush Muhly
(Flourensia cernua/Muhlenbergia porteri)
Tarbush/Alkali Sacaton
(Flourensia cernua/Sporobolus airoides)

Distr: western alluvial fans.

Table 2 (Continued).

Non-Dune Grassland

Gypgrass/Coldenia Consociation
(*Sporobolus nealleyi/Coldenia hispidissima*)

Incl:Fourwing Salt Bush/Gypgrass)
(Atriplex canescens/Sporobolus nealleyi)
Hairy Coldenia/Gyp Moonpod
(Coldenia hispidissima/Selinocarpus lanceolatus)

Distr:southwestern non-dunal flats with gypsum outcrops.

Alkali Sacaton/Poison Milkweed -- Alkali Sacaton/Torrey Mormontea Association
(*Sporobolus airoides/Asclepias subverticillata -- S. airoides/Ephedra torreyana*)

Incl:Fourwing Salt Bush/Alkali Sacaton)
(Atriplex canescens/Sporobolus airoides)
Fremont Cottonwood/Seepwillow
(Populus fremontii/Baccharis glutinosa)
Fremont Cottonwood/Indian Ricegrass
(Populus fremontii/Oryzopsis hymenoides)

Distr: southern non-dunal flats; occasionally in interdunal areas.

Alkali Sacaton/Sparse Consociation
(*Sporobolus airoides/*Sparse)

Incl:Alkali Sacaton/Torrey Mormontea
(*Sporobolus airoides/Ephedra torreyana*)

Distr: southern non-dunal flats; occasionally in interdunal areas.

Inter-Dune Gypsum Grassland

Gyp Grama/New Mexico Bluestem -- Gyp Grama/Torrey Mormontea Association
(*Bouteloua breviseta/Schizachyrium neomexicanum -- B. Breviseta/Ephedra torreyana*)

Incl:Gyp Grama/Alkali Sacaton
(Bouteloua breviseta/Sporobolus airoides)
Fourwing Saltbush/Alkali Sacaton
(Atriplex canescens/Sporobolus airoides)
Fremont Cottonwood/Indian Ricegrass
(Populus fremontii/Oryzopsis hymenoides)

Distr: interdunal areas of parabolic and transverse dunes systems peripheral to the Heart of Dunes area.

New Mexico Bluestem/Sand Verbena-New Mexico Bluestem/ Indian Rice Grass Association
(*Schizachyrium neomexicanum/Abronia angustifolia- Schizachyrium neomexicanum/Oryzopsis hymenoides*)

Incl:Gyp Grama/New Mexico Bluestem
(*Bouteloua breviseta/Schizachyrium neomexicanum)*
Indian Ricegrass/Sand Verbena
(Oryzopsis hymenoides/Abronia angustifolia)

Distr: interdunal areas, primarily associated with parabolic dunes of the Heart of Dunes area.

Table 2 (Continued).

Non-Vegetated

Barren Playa

Distr: Lake Lucero

Barren Dunes

Distr: Heart of Dunes

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DISCUSSION

The map generated for White Sands National Monument indicated that the approach used for the classification of the vegetation using satellite imagery can be used to produce highly detailed 1:24,000 scale vegetation maps. In this case, many of the vegetation map units could be taken to the community type level. We have confidence that, for most of the community types, the accuracy levels are acceptable and will be sustained in any subsequent accuracy assessment. Pattern distribution of community types among the dunes and flats on the map corresponds well to that observed in the field. Only three of the vegetation Series could not be spectrally discriminated and mapped as independent units. These were the *Larrea tridentata* (creosote bush), *Flourensia cernua* (tarbush) Series, and the riparian *Populus fremontii* (Fremont cottonwood) Series.

With respect to the Creosote and Tarbush Series this was in part due to sample allocation. More ground points were concentrated in the eastern half of the Monument, among gypsum dunes and flat types. This led to well documented units in the heart of the Monument and more unresolved areas near the edges where creosote and tarbush are more common. We believe that these types can be differentiated spectrally with enhancements in the image analysis targeted at the types in conjunction with more ground data.

The major constraint on identifying *Populus fremontii* communities is due to the spatial resolution limitations in the image. Since these communities always occur in small patches -- sometimes smaller than a pixel size -- spectral responses become averages of a community itself plus neighboring communities. Hence, a spectral signature can not be resolved for the community and appears either transitional or is classified with the neighboring spectral classes.

Community types described here are coincident to some extent to the associations reported by Reid (1979). However, some of the dominant species we identified in extensive areas (e.g. *Sporobolus nealleyi*) were not mentioned in his work. Patrick's (1980) description of the Monument flora is more detailed, and the communities described are more similar to ours, but it is restricted to the parabolic dune vegetation.

RECOMMENDATIONS

There are three areas of interest where we would suggest further work:

1) Map Accuracy Assessment and Map Revision

The map presented here represents a first iteration based on a single ground point validation set without a quantitative accuracy assessment. On a qualitative basis the map appears to have a good spatial structure and resolution, but a quantitative accuracy assessment would further enhance confidence in the map. This will require the establishment of an independent data set to test individual map unit delineations for their composition. This can be done by establishing a stratified random grid of ground points that have been classified according to the vegetation classification provided. This grid can be enhanced through the use of air-borne videography coupled with GPS to increase the sampling density at a reduced cost.

One of the strengths of a digital satellite image map is that as new data is acquired, revision is relatively easy compared to photo-interpretive maps. Hence, the above mentioned sampling grid can be used not only for accuracy assessment of the current map, but the data can be subsequently used to revise spectral class allocation leading to the next iteration and improvement of the map. Further, new imagery from a different date can be acquired and directly compared to the previous image. Such a multi-temporal analysis may improve the resolution of difficult classes on the map. The current map should be viewed as a working tool that will be iteratively revised on an ongoing basis.

2) Monitoring for Vegetation Change

The Monument is responsible for the protection of a wide variety of vegetation communities, many of which may be unique to the immediate area. It is important to assess the impact of various management strategies on vegetation community dynamics and processes through a long term monitoring program. For example, significant changes are expected to occur in the vegetation of the area after exclusion of the exotic *Orix gazella*. Although a larger number of *Orix* were observed on the western part of the Monument, many tracks, as well as a few animals, were also seen on the dunes. Their impact on the unique communities and environment is not currently well understood, but can be evaluated through permanent monitoring sites such as those we have provided in Appendix 4. Also, repeated satellite image analysis through time as part of an iterative mapping process or independently of the mapping could prove to be effective and cost efficient as a monitoring tool. It could be particularly effective in environments and among communities that are well defined spectrally and spatially.

3) Vegetation Classification Revision and Ecological Research for Ecosystem Management

The vegetation classification presented here should be considered preliminary in nature and subject to iterative improvement in a similar fashion to, or in conjunction with, mapping revisions. Currently, the classification is based on minimum documentation -- community types are represented by one complete releve and a soil profile description, and varying numbers of the less detailed validation plots. As a rule of thumb, a minimum of five plots with complete vegetation, soils and landform descriptions are required to consider a community type well documented and established as part of the statewide vegetation classification of the New Mexico Natural Heritage Program. Of particular interest are the special communities of the dunelands and gypsum outcrops that may be unique to the Monument and surrounding adjacent areas of White Sands Missile Range. More data are needed on these communities for classification purposes, but also, well designed studies and experiments would increase our understanding of the community dynamics (succession) and processes (nutrient cycling, water usage), which will in turn enhance management on an ecosystem level.

For some of the more regionally widespread types which are present on the Monument, a single releve is adequate "verification" that the type exists, but one plot does not convey the range of variation that may occur. Further, some of the communities such as those from the Tarbush and Creosote Series may be widespread elsewhere, but the current sampling density and allocation probably under-represents community types in the classification. Overall, further documentation of community types with more releves and soil profiles is strongly suggested to lead to a comprehensive classification with complete community type descriptions and associated information on the environmental characteristics, ecological processes and management implications.

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